Chapter 5 EO - SPECTRAL IMAGERY

The previous chapters have illustrated basics of optics, and panchromatic imagery. An increasingly important element in remote sensing is the ability to look beyond the purely "literal". This means making use of remote sensing information beyond elements such as size and shape, and looking at the 'color' of objects to identify them.

A Reflectance of Materials

The reflectance of most materials varies with wavelength. This allows spectral imagers, such as those on the Landsat missions, to distinguish between different materials. Distinguishing between different minerals is a fairly common goal for such work.

In figure 5-1 different aspects of reflective spectra are briefly illustrated. These spectra are the fingerprints of the elements, and derive from the fundamental atomic characteristics of the elements, as first indicated in chapter 2 for the Bohr model of the hydrogen atom. One of the more important, and dramatic spectral features found in remote sensing is the "IR ledge" at 0.7μ, as found in figure 5-2. This dramatic rise in reflectance with wavelength causes vegetation to be bright in the infrared. Old style black-and-white infrared film would show vegetation as bright, for example. In the military, one tries to design camouflage that can mimic this behavior.

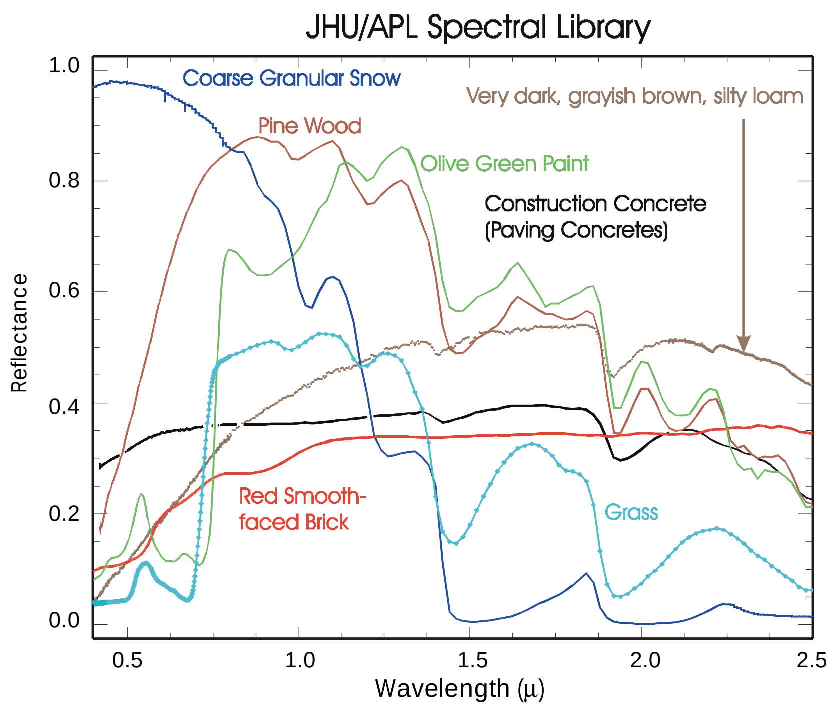


Figure 5.1 Comparison of some man-made and naturally occurring materials. Note how the olive green paint mimics the grass spectrum in the visible to NIR, but then deviates.

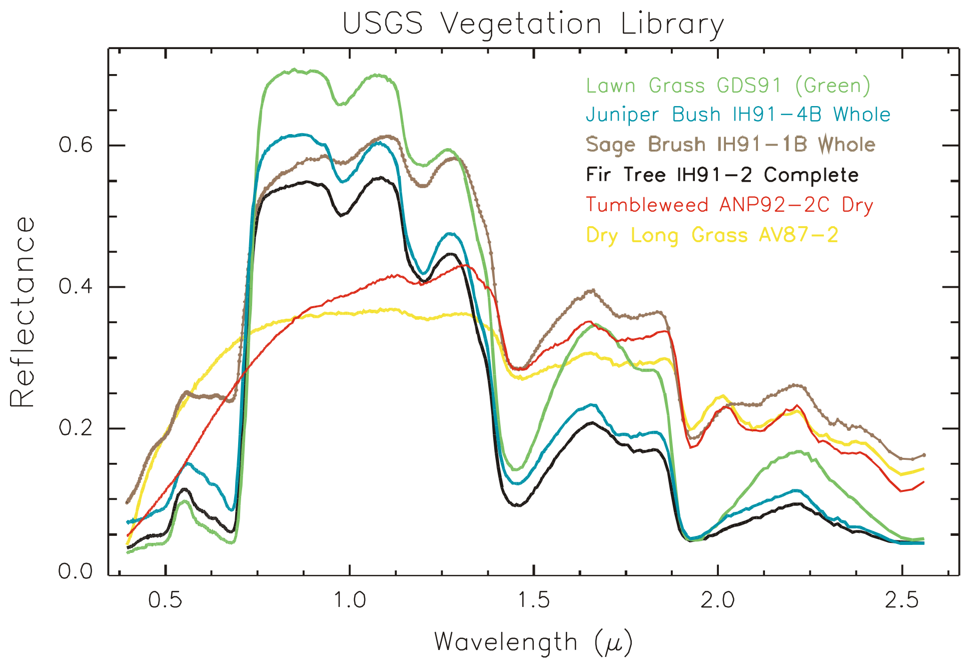


Figure 5.2 Sample vegetation spectra.
Clark, R. N., G. A. Swayze, A.J. Gallagher, T.V.V. King, and W.M. Calvin, 1993, The U. S. Geological Survey, Digital Spectral Library: Version 1: 0.2 to 3.0 microns, U.S. Geological Survey Open File Report 93-592, 1340 pages.

The sequence of vegetation spectra is meant to indicate some of the primary characteristics of vegetation:

a) the IR ledge at 0.7 μ, as noted above;
b) the lack of this feature in dry, brown, or senescent vegetation,
c) the dramatically higher reflectance in the IR vs. the small peak in the green (vegetation is dark as we normally see it).

Not indicated here, but important when viewing vegetation from above, is that the spectrum of a leaf is not the spectrum of a tree. This means that when foliage is viewed from above, observations will generally included the (shaded) ground below the vegetation, and the filtered sunlight reflecting from different elements of the foliage.

B Landsat

In late July 1972 NASA launched the first Earth Resources Technology Satellite (ERTS-1). The multispectral data provided by the on-board sensors led to an improved understanding of crops, minerals, soils, urban growth, and many other Earth features and processes. The name of the satellite, and those that followed, was soon changed to Landsat. These have been the primary earth resources satellites ever since, utilizing multispectral imagery with a spatial resolution of 30 meters. The most recent addition to the series is Landsat 7. At launch, this satellite, including the instrument and fuel, weighed approximately 4,800 pounds (2,200 kilograms). It is about 14 feet long (4.3 meters) and 9 feet (2.8 meters) in diameter. One of the first Landsat 7 images is shown below.

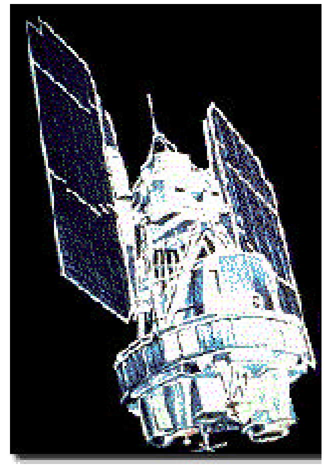


Figure 5-3 ERTS-1

Satellite	Launched	Sensors	Resolution (meters)	Altitude (km)	Data Link
Landsat 1 (ERTS-A)	July 23, 1972 - January 6, 1978	MSS RBV	80 80	917	Direct Downlink w/recorder (15Mbps)
Landsat 2	January 22, 1975 - February 25, 1982	MSS RBV	80 80	917	""
Landsat 3	March 5, 1978 - March 31, 1983	MSS RBV	80 30	917	""
Landsat 4	July 16, 1982 - *	MSS TM	80 30	705	Direct Downlink w/TDRSS (85Mbps)
Landsat 5	March 1, 1984 - date	MSS TM	80 30	705	""
Landsat 7	April 15, 1999 - date	ETM+ (pan)	30 15	705	Direct Downlink w/solid state recorders (150 Mbps)

*TM data transmission failed in August 1993, satellite used for maneuver testing

Landsat 6 was launched aboard a Titan II space launch vehicle from Vandenberg Air Force Base, Calif., Oct. 5, 1993. Indications were that the spacecraft separated from the booster at the appropriate time and location, but did not achieve orbit. The NOAA review board confirmed this and attributed the failure to a ruptured hydrazine manifold. The ruptured manifold rendered the satellite's reaction engine assemblies useless because fuel could not reach the engines. As a consequence, there was a failure to maintain attitude control during the apogee kick motor (AKM) burn. This failure caused the spacecraft to tumble during the AKM burn and not accumulate sufficient energy to attain orbit.

Figure 5-4. SF visible image from Landsat 7, April 23, 1999, flight day 9, orbit 117. ~1830Z With special thanks to Rebecca Farr, NESDIS/NOAA. Not yet on WRS, the scene is offset 31.89566 km east of nominal scene center. (Path 44 Row 34)

1 Orbit

The Landsat missions have been polar orbiters, in circular orbits, currently at an altitude of 705 km. An inclination of ~97° makes them sun-synchronous. Equatorial crossings were set at 0930 am for Landsats 1,2,3; 1030 AM for Landsats 4 and 5, 1000 AM for Landsat 7. These latter missions have orbit tracks set for 14.5 orbits per day, with 233 unique orbit tracks. The repeat cycle is every 16 days.

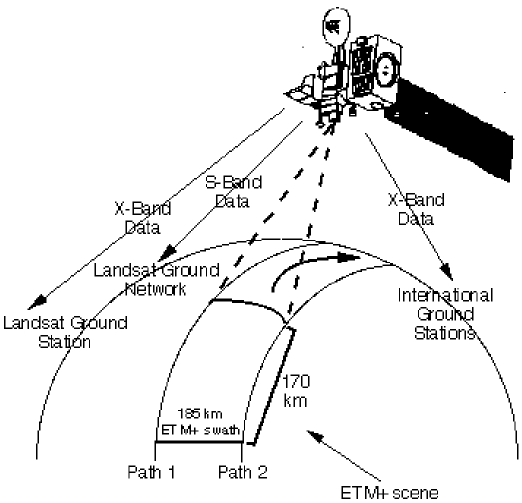


Figure 5.5

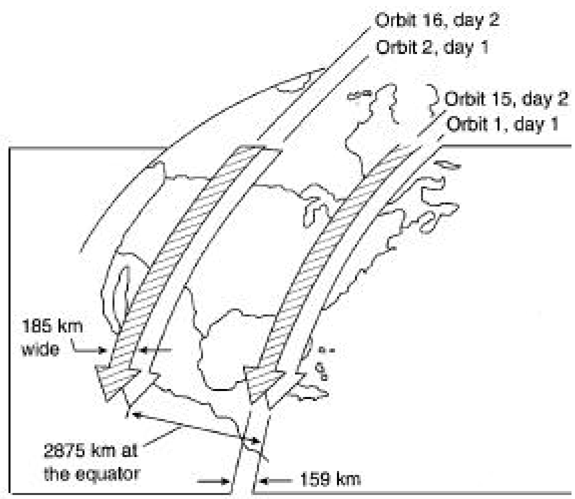


Figure 5.6

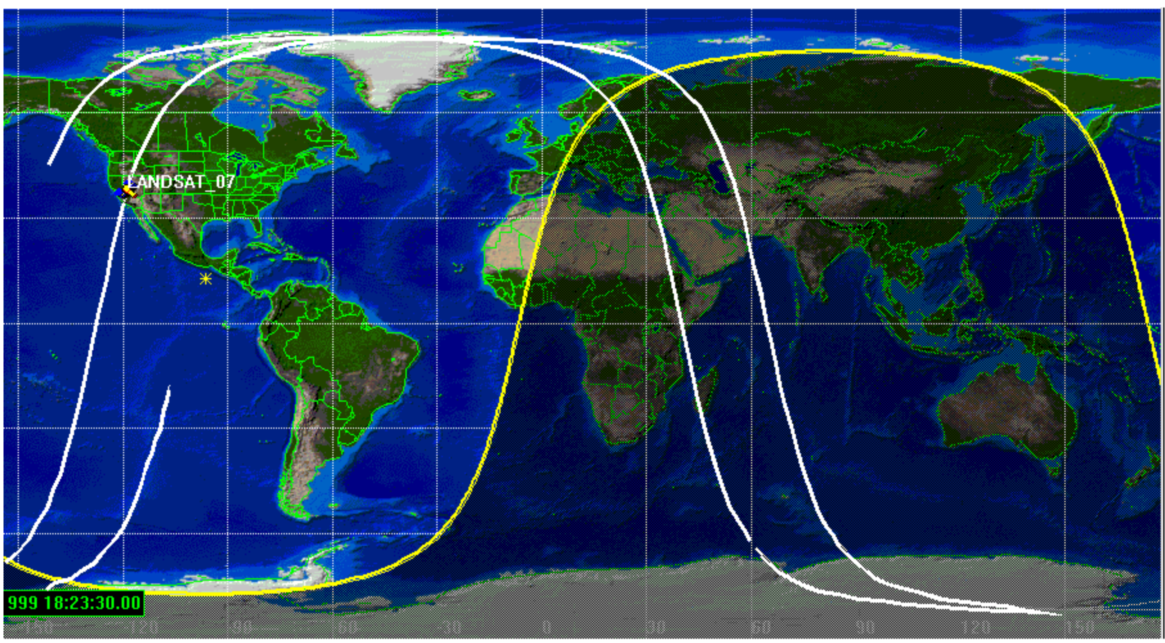


Figure 5.7 This is the orbit track corresponding to the San Francisco image shown above. The small yellow spot just below Mexico City is the sub-solar point, April 23, 1999, ~1830Z.

2 Sensor - Thematic Mapper

The first Landsats flew with a multispectral imager termed the MSS, and a TV-like sensor termed the Return Beam Vidicon. Beginning with Landsat 4, the prime instrument has been the Thematic Mapper, though the MSS was also carried to maintain continuity in archival, synoptic data sets. The TM sensor has provided 7 bands of spectral information at 30-meter resolution since 1982. On the most recent vehicle, Landsat 7, the instrument has been revised, and is termed the Enhanced Thematic Mapper - plus, or ETM+. The instrument has been revised to improve spatial resolution in the LWIR channel, and a new panchromatic band has been added with relatively higher spatial resolution (15 m). The discussion that follows addresses the most modern sensor.

a Optics

The optical path begins with a flat scan mirror oscillating with a period of 142.925 ms, scanning at 4.42 radians/s over a range of 0.2686 radians (15.39°). (60.74 ms scan, 10.72 ms to reverse.) The telescope is a Ritchey-Chretien design, a Cassegrain variant. The primary mirror (outer) aperture is 40.64 cm; the clear inner aperture is 16.66 cm. The effective focal length is 2.438 m, f/6. The mirror is ultra-low expansion glass, coated with silver. FOV: ±0.27°, IFOV: 42.5 μ radians.

The Relay Optics consists of a graphite-epoxy structure containing a folding mirror and a spherical mirror which are used to relay the imaged scene from the prime focal plane to the Band 5, 6 and 7 detectors on the cold focal plane. The characteristics of the relay optics are listed in the table below. The relay optics provides a magnification of 0.5. This magnification is used because of the reduced physical size of the band 6 detectors.

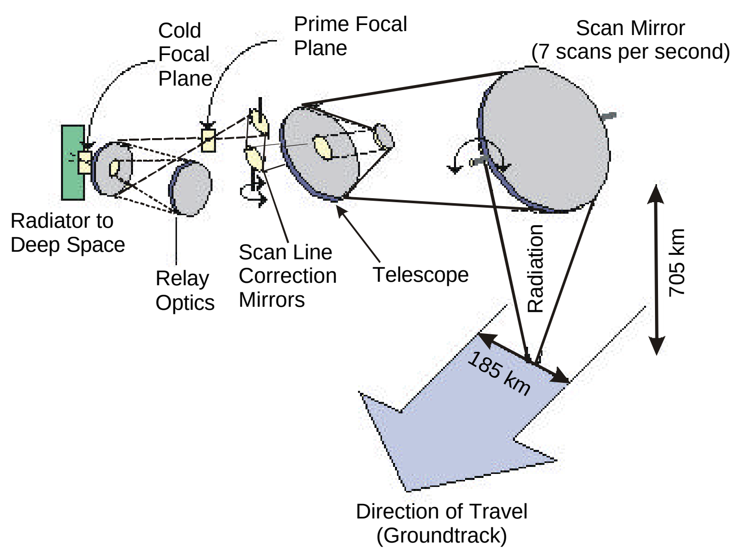


Figure 5.8 Landsat ETM+ Optical path.

Relay Optics Design Parameters	
Folding mirror clear aperture outer diameter	7.98 cm
Folding mirror clear aperture inner diameter	1.364 cm
Spherical mirror clear aperture diameter	14.067 cm
Magnification	0.5
F/#	3.0
Mirror material	ULE glass
Mirror coating	Aluminum, SiO overcoat

b Focal Planes

The ETM+ scanner contains 2 focal planes that collects, filters, and detects the scene radiation in a swath, 185 km wide, as it passes over the earth. The primary (warm) focal plane consists of optical filters, detectors, and preamplifiers for 5 of the 8 ETM+ spectral bands (bands 1-4, 8). The second focal plane is the cold focal plane (90 K), which includes the optical filters, infrared detectors, and input stages for ETM+ spectral bands 5,6, and 7.

Each band is comprised of two staggered rows of detectors with a center-to-center spacing between subsequent detectors in each row about twice the detector dimension and spacing between the rows just slightly more than that. This is done because there are readout electronics between the detectors. A scan mirror sweeps in the east-west direction as the spacecraft moves at about 6.7 km/s downtrack. The scan mirror operates at 7 Hz, so in half a period, or 71.4 msec, the spacecraft moves 480 meters downtrack.

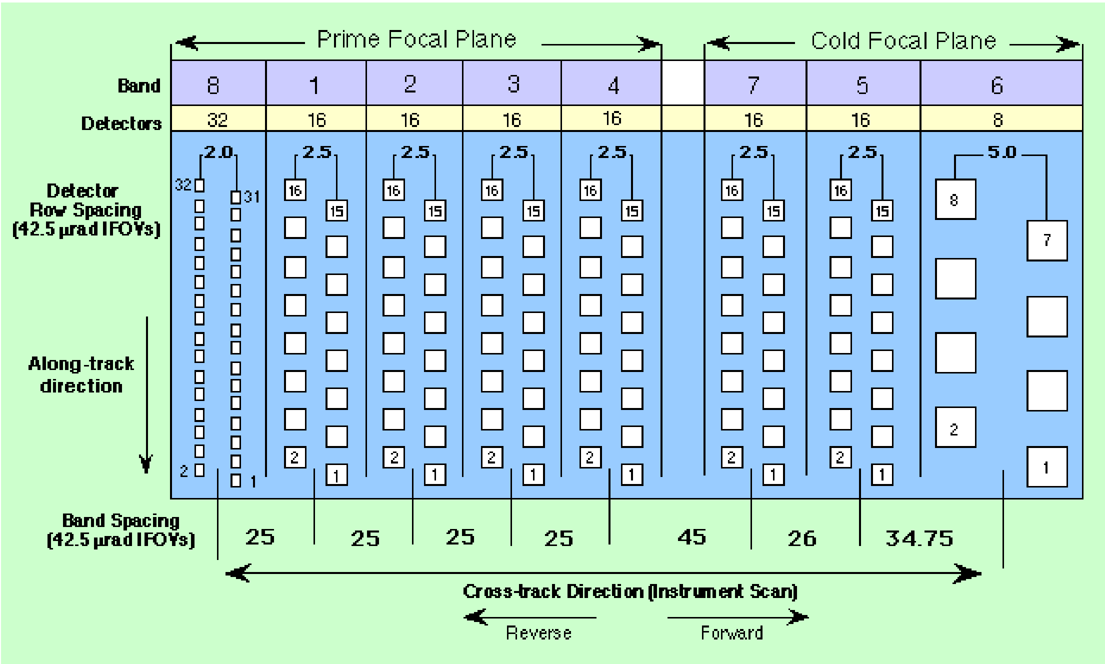


Figure 5.9

c Prime Focal Plane

The Prime Focal Plane Array is a monolithic silicon focal plane made up of five detector arrays: Band 1 through Band 4 and the Pan Band (8). The arrays for Bands 1 through 4 contain 16 detectors divided into odd-even rows. The array for the Pan Band contains 32 detectors also divided into odd-even rows. The system focus is optimized for the Pan Band which has the highest spatial resolution. The preamplifiers are mounted on the Prime Focal Plane Assembly, and consist of two stacks of flat hybrid modules. On top of each stack is a cylindrical black radiative cooling tower to help dissipate the heat from the preamplifiers.

Prime Focal Plane Assembly Design Parameters		
Parameter	**Bands 1 through 4**	**Pan Band**
Number of detectors	16 per band	32
Detector Size	103.6µ ×103.6µ	51.8 µ × 44.96µ
Detector Area	1.074×10^{-4} cm^2	2.5×10^{-5} cm^2
IFOV size	42.5 µ	21.3 µ× 18.4 µ
Center to center spacing along track	103.6 µ	51.8 µ
Center to center spacing between rows	259.0 µ	207.3 µ

The addition of a higher spatial resolution 'pan' band required the addition of a single staggered pair of rows of 16 detectors (32 detectors total making an equivalent 32 element line array downtrack) to the warm focal plane, each detector one-half the dimensions of the existing visible/near-IR band detectors. Of course, the new detectors also required the necessary preamplifiers, readout circuitry, and off-FPA electronics to produce the data. This band has a data rate four times that of the other visible bands. This increased the data rate of the sensor by about 70%.

d Cold focal Plane

There are 16 cooled indium antimonide (InSb) detectors for bands 5 and 7. Finally, for the LWIR, there are 8 cooled mercury cadmium telluride (HgCdTe) photo-conductive detectors for band 6. The detectors for bands 1-4, 5, and 7 each have 30-m resolution, the LWIR detector has 60 m resolution (an improvement over the 120 m resolution on TM). The detectors are arranged to have the same 480-m coverage downtrack.

Cold Focal Plane Design Parameters		
Parameter	**Bands 5 and 7**	**Band 6**
Number of detectors	16 per band	8
Detector Size	48.3µ × 51.82 µ	104µ × 104 µ
IFOV size	42.5 µ	42.5 µ × 85.0 µ
Center to center spacing along track	51.8 µ	104 µ
Center to center spacing between rows	130 µ	305 µ

With thanks to Dr. Carl Schueler, Director Advanced Concepts, Raytheon, May 1999.

And http://ltpwww.gsfc.nasa.gov/IAS/handbook/

e Spectral Response

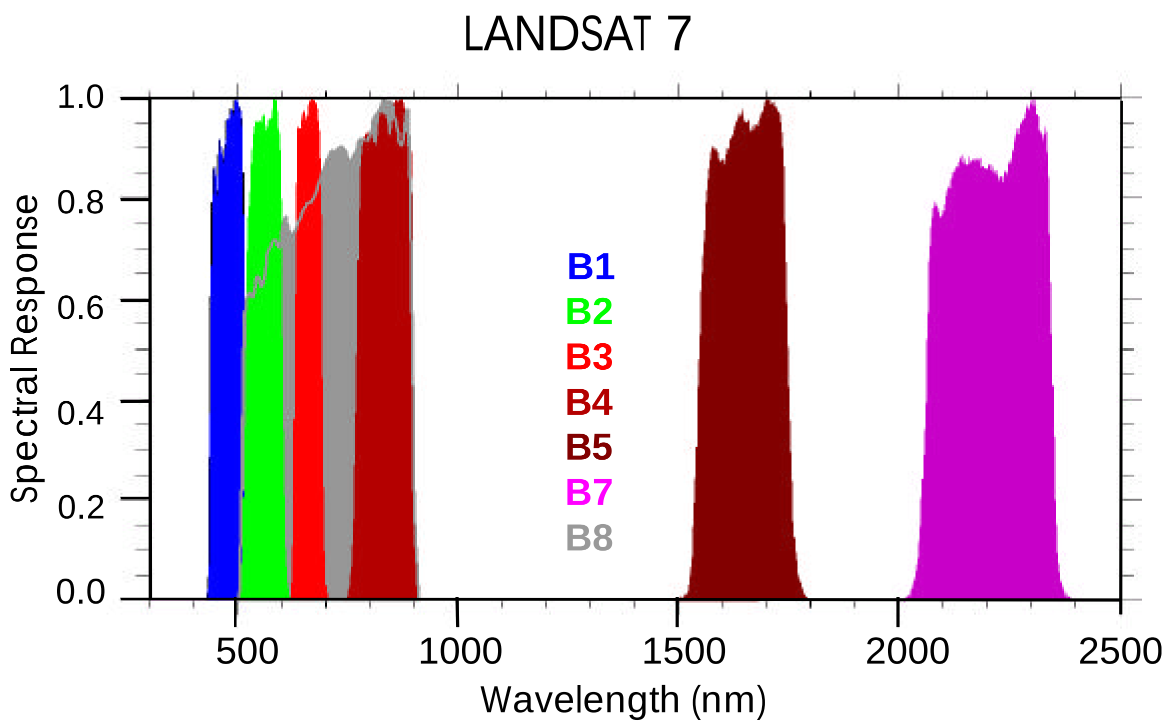
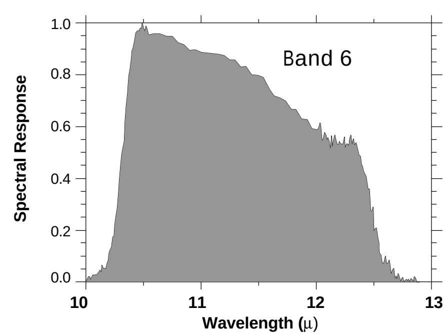


Figure 5.10 The Landsat 7 spectral bandbass response functions are plotted here as a function of wavelength. These values are from the ground calibration numbers provided by NASA/GSFC. Note that the higher resolution pan-chromatic band cover the same region as bands 2,3, and 4, but does not extend into the blue. This is to avoid the scattering effects in the atmosphere at shorter wavelengths.
Above: Bands 1-5, 7 (VNIR, SWIR).
Right: Band 6 (LWIR)



IKONOS multispectral data are taken over the same four bands as shown here for Landsat Bands 1-4, at 4-meter resolution.

f Spatial resolution - swath

Summarizing the above figures, the wavelength bands and spatial resolution for the ETM+ are as given here:

Band	Detector	Wavelength (nanometers)	Resolution (m)
1	Si	450-520 (VIS, blue)	30
2	Si	520-600 (VIS, green)	30
3	Si	630-690 (VIS, red)	30
4	Si	760-900 (NIR)	30
5	InSb	1550-1750 (SWIR)	30
6	HgCdTe	10.40 to 12.5 microns, thermal	60*
7	InSb	2090-2350 (SWIR)	30
Pan	Si	520-900	15

* 60 meter resolution for band 6 on Landsat 7 - 120 m on earlier missions.

g Dynamic range

An important element of all imagery is the question of dynamic range - the range of values from dark to bright that characterize the data. Landsat provides a fairly traditional 8 bit dynamic range - 0 to 255 DN. (The Landsat 7 ETM, Band 6 is now telemetered in two ranges, HI and LO, to extend the dynamic range of the data in that channel). Note that by contrast IKONOS data are 11 bit, enabling a dynamic range of 0-2047. Since most systems are designed for the brightest nominal targets, this difference in dynamic range is an indication of the sensor's ability to "see" into shadows, and to discriminate structure on dark targets.

h Data Rate

The Landsat missions have been designed to work with direct downlinks, suupplemented with some form of storage. Earlier missions carried tape recorders, which have all the undesirable characteristics of any moving, mechanical system on a satellite - ultimately they wear out. Beginning with Landsat 7, a solid state recorder (SSR) has been implemented.

The ETM+ instrument takes the data and separates the data into two formats. Format 1 (channel 1 also referred to as channel I contains bands 1-6 and format 2 (channel 2 also referred to as channel Q contains bands 6, 7, and 8 (PAN). Each format is transferred at 75 Mbps to a baseband switching unit (BSU) where the data is modulated. The data are then either downlinked in real-time to the Landsat Ground Station located at Sioux Falls, South Dakota, via an X-band link at a combined aggregate rate of 150 Mpbs, or recorded on the SSR. The data recorded on the SSR can be played back using one or two 150 Mbps bitstreams and downlinked to the LGS via the X-band link. When the spacecraft flies over LGS, it downlinks two 150 Mbps data streams, either 1 real-time and 1 playback, or 2 playbacks. Therefore, when the data is transmitted to the LGS, it is a combined rate of 300 Mbps, 150 Mbps bitstreams from the ETM+ and 150 Mbps bitstreams from the SSR or two 150 Mbps bitstreams from the SSR.

Reference:
http://caster.gsfc.nasa.gov/lps/ExtIntFaces/satellite.html

i Brief Review exercise - data rates

How do the various numbers described above relate to one-another? Let us estimate the data rate implied with a 185 km swath width, at 30-m resolution.

1) First, how many pixels per "line" for one of the standard channels? $\frac{185 km}{30 m / pixel} = 6000\, pixels / scan\ line$ (The correct answer is 6928 - there is some overlap in the pixels)

2) How many bits, or bytes, are there per scan line? $8\ bits/pixel \times 6000\ pixels/line$ $= 4.8\times10^4$ bits per scan line

3) How long is the satellite accumulating photons for one scan line?

$\tau = \dfrac{30m}{7\times10^{3}m/s} = 0.0043s$ or 4.3ms (The actual time is 16 times longer, because of the focal plane design, but this answer will do for our purposes.)

4) So what is the implicit data rate? $\dfrac{4.8\times10^{4}bits}{4.3\times10^{-3}s} = 11.2\times10^{6}\dfrac{bits}{s} \approx 1.4MB/s$. So, one channel produces data at the rate of 1.4 Megabytes per second. Historically there were 7 channels, so some 85 Megabits/s, or 10 MB/s. This rate has gone up by the influence of the extra channel 6 gain setting, and the 4x panchromatic channel, leading to the 150 Mb/s found on Landsat 7, using a 8.2 GHz (X-band) downlink.

j Student assignment: What is the current TDRSS configuration?

number of satellites, locations
transponder(s) - frequency, bandwidth
ground station(s) locations

C SPOT (Systeme Probatoire d'Observa tion de la Terre)

The French have their own version of Landsat, the Systeme Probatoire d'Observation de la Terre, or SPOT. The spectral capability of SPOT is limited compared to Landsat, but SPOT carried the highest spatial resolution PAN sensor available to the civilian community for a number of years. The orbits are all at 822-km altitude, with a 26 day repeat cycle, sun-synchronous, 10:00 local time. SPOT 1, 2, and 4 are all working as of mid-1999.

	SPOT 1	SPOT 2	SPOT 3	SPOT 4
Launch Date (YY/MM/DD)	1986/02/22	1988/03/01	1993/09/26	1998/03/24
Mass	1750 kg	1810 kg	1907 kg	2700 kg
Solar Array	1 KW	1 KW	1 KW	2.1 KW
Solar Panels	8.14 m	8.14 m	8.14 m	8.03 m
Altitude (at equator)	822 km	826 km	822 km	824 km
Orbital period	101.4 min	98.8 min	101.4 min	101.4 min
Mean Motion (Revs/Day)	14.20	14.20	14.17	14.20
Inclination	98.79	98.73	98.64	101.4 min
Main Structure (meters)	$2 \times 2 \times 4.5$	$2 \times 2 \times 4.5$	$2 \times 2 \times 4.5$	$2 \times 2 \times 5.6$
Telemetry (carrier freq.)	8.253 GHz	8.253 GHz	8.253 GHz	8.253 GHz
Image data rate	2×25 Mbits/s	2×25 Mbits/s	2×25 Mbits/s	2×25 Mbits/s
Onboard storage capacity	2×22 minutes*	2×22 minutes*	2×22 minutes*	2×40 minutes* + 3 minutes**

*Tape, **Solid State memory

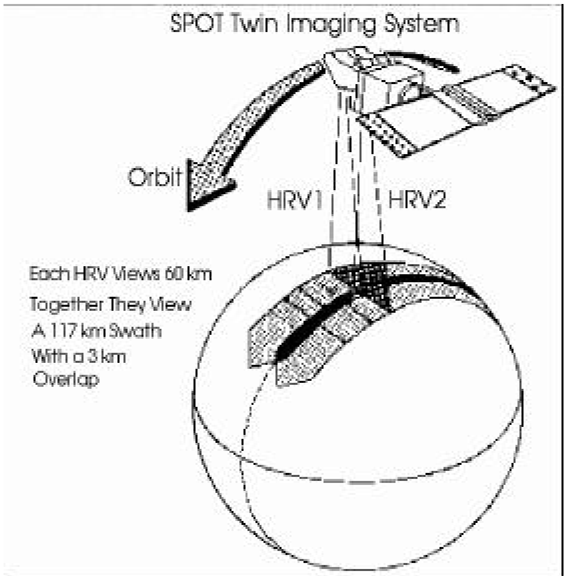


Figure 5.10

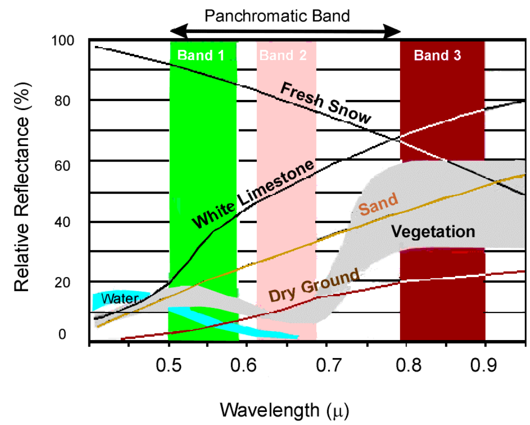


Figure 5.11 SPOT 1, 2, 3

1 HRV sensor - pan/spectral - both are 60 km swath

The SPOT HRV sensors use paired linear arrays of 6000 pixels each for the high resolution panchromatic imager, as opposed to the single detector, scanning mirror with Landsat. The spectral channels use 3000 pixels each. The system uses 'Push broom' scanning, but with a significant off-nadir pointing capability (about 23° off-nadir). The two sensors can be pointed independently but apparently are normally operated to give a 120-km swath directly below the satellite (see Figure 5.10). The ability to use off-nadir pointing enhances the ability to do stereo pairs, and can be used to shorten revisit intervals.

a Imaging Modes - Spatial and Spectral Resolution

Note that on SPOT 4, an additional SWIR band was added, and a change in the spectral bandpass occurred for the panchromatic channel. On SPOT 4, the hi-resolution mode is in the red band. Compare this to the Landsat 7 panchromatic band.

	Resolution	SPOT 1, 2, 3 (XS)	SPOT 4 (XI)
Band 1	20 m	500-590 nm (green)	500-590 nm (green)
Band 2	20 m	610-680 nm (red)	610-680 nm (red)
Band 3	20 m	790-890 nm (ir)	790-890 nm (ir)
Band 4	20 m	-	1580-1750 nm (SWIR)
Hi-Res	10 m	P mode - 510-730 nm	M mode - 610-680 nm

M - Monospectral, P- Panchromatic

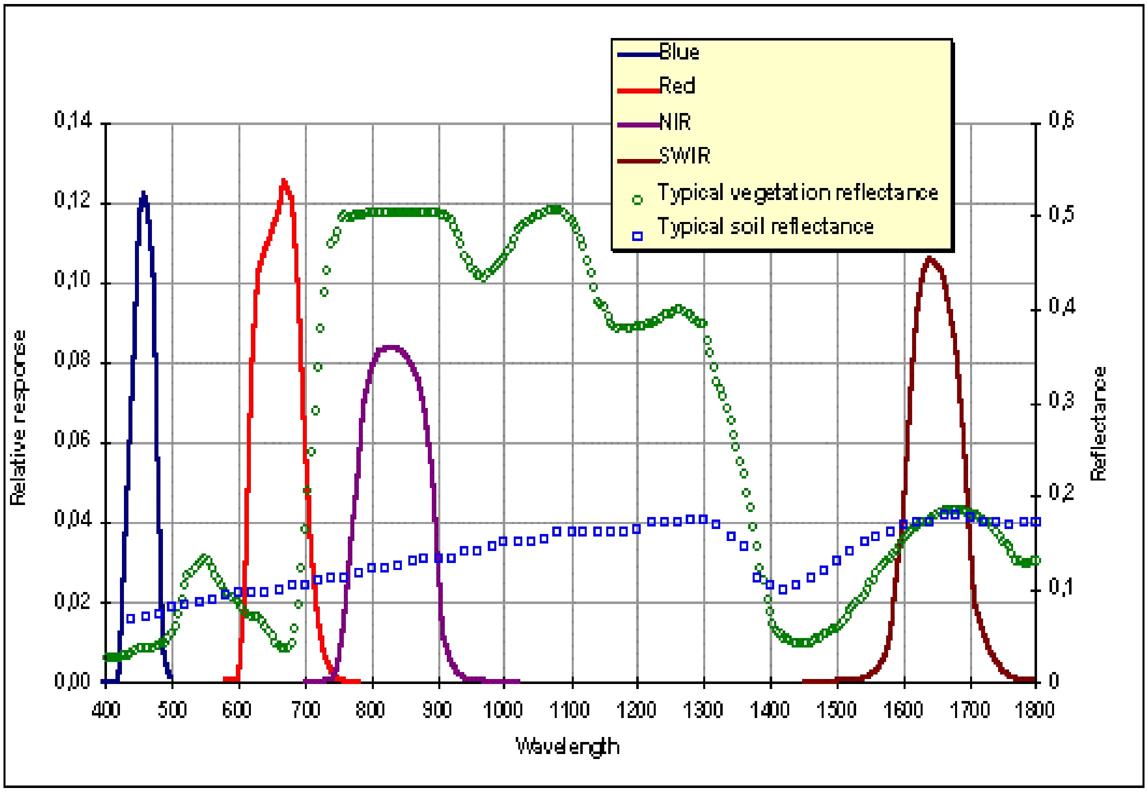


Figure 5.12 SPOT 4 spectral responses. Notice that bands 2 and 3 are designed to distinguish the vegetation signature at the 700 nm IR ledge.

SPOT data from San Diego were illustrated in chapter 1 for the high-resolution panchromatic sensor. The spectral imagery from SPOT historically have been less widely used, when LANDSAT data are available.

D Indian Remote Sensing Satellites (IRS)

India has evolved a healthy remote sensing effort, and a substantial commercial presence beginning roughly with IRS-1C and IRS-ID. These vehicles mass ~1,350 kg, and are in 820 km polar orbits. The solar array generates more than 800 W. Both IRS-1C and 1D produce 5.8-meter panchromatic (0.50.75 µm - black and white) imagery, which is resampled to five-meter pixel detail, at 6 bit resolution. This spatial resolution, as of early 1998, was the best of any civilian remote sensing satellites in the world.

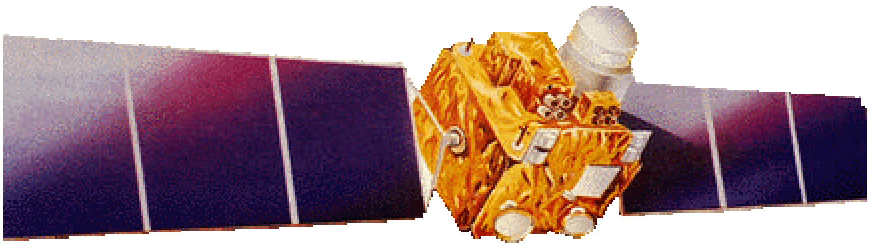


Figure 5.13 IRS

These satellites are also equipped with two-band Wide Field Sensors (WiFS) that cover a 774-square-kilometer (481-square-mile) area in a single image, as well as LISS-3 4-band sensors that provide 23.5-meter resolution multispectral coverage. The 23.5-meter resolution imagery is resampled to produce 20-meter pixel detail. The spacecraft also carry a 2-channel (0.62-0.68 and 0.77-0.86 µm) wide-field sensor (190 m resolution).
The IRS C, D Pan sensor sacrifices swath width for its higher resolution. However, it can be pointed off the orbit path which allows 2 to 4 day revisits to specific sites. http://www.fas.org/spp/guide/india/earth/irs.htm

IRS-1C was launched into polar orbit on the 28th of December, 1995 by a Russian launch vehicle. Its payload was activated in the first week of January 1996. IRS-1D was launched 28 September 1997. It was also supposed to have gone into 800 km circular orbit, but initially went into an 821 × 327 km orbit. The orbit was corrected to 826 × 738 km using onboard fuel. This will shorten its operating life.

Sensor	PAN	LISS-III			WiFS		
Spatial resolution	5.8 m	23 m (VIS and NIR) 70 m (SWIR)			188 m		
Swath-width	70 km	142 km			810 km		
Spectral coverage	Pan-chromatic	Band 2 Band 3 Band 4 Band 5	520 - 590 nm 620 - 680 nm 770 - 860 nm 1550-1700 nm	green red NIR SWIR	Band 3 Band 4	620-680 nm 770-860 nm	red NIR
Radiometric Resolution, Quantisation	6 bit	7 bit			7 bit		

Note the modest dynamic range, and compare to Landsat and SPOT.

E Imaging Spectroscopy

Imaging Spectroscopy is the acquisition of images where for each spatial resolution element in the image a spectrum of the energy arriving at the sensor is measured. These spectra are used to derive information based on the signature of the interaction of matter and energy expressed in the spectrum. This spectroscopic approach has been used in the laboratory and in astronomy for more than 100 years.

AVIRIS: General Overview

AVIRIS is an acronym for the *A*irborne *V*isible *I*nfra*R*ed *I*maging *S*pectrometer. AVIRIS is a world class instrument in the realm of Earth Remote Sensing. It is a unique optical sensor that delivers calibrated images of the upwelling spectral radiance in 224 contiguous spectral channels (also called bands) with wavelengths from 400 to 2500 nanometers (nm). The instrument flies aboard a NASA ER-2 airplane (a U2 plane modified for increased performance) at approximately 20 km above sea level, at about 730 km/hr.

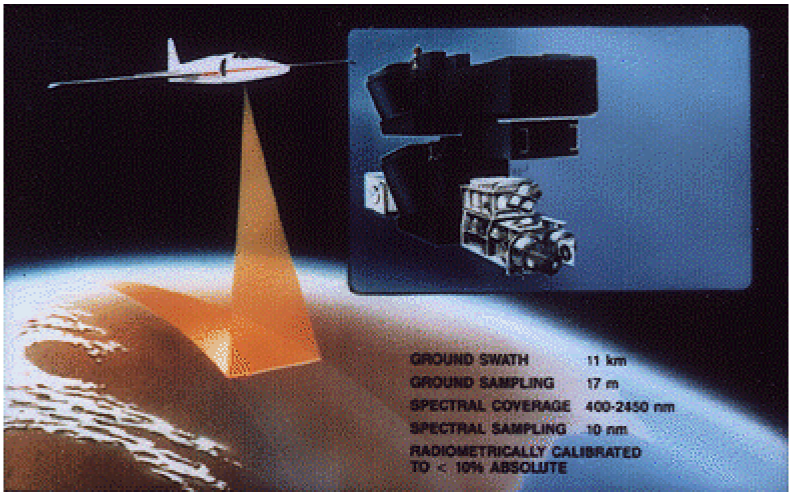


Figure 5.14

The AVIRIS instrument contains 224 different detectors, each with a wavelength sensitive range (also known as spectral bandwidth) of approximately 10 nanometers (nm), allowing it to cover the entire range between 380 nm and 2500 nm. When the data from each detector is plotted on a graph, it yields a spectrum. Comparing the resulting spectrum with those of known substances reveals information about the composition of the area being viewed by the instrument.

AVIRIS uses a scanning mirror to sweep back and forth ("whisk broom" fashion), producing 614 pixels for the 224 detectors each scan. Each pixel produced by the instrument covers an approximately 20 meter square area on the ground (with some overlap between pixels), thus yielding a ground swath about 11 kilometers wide.
http://makalu.jpl.nasa.gov/html/aboutav.html

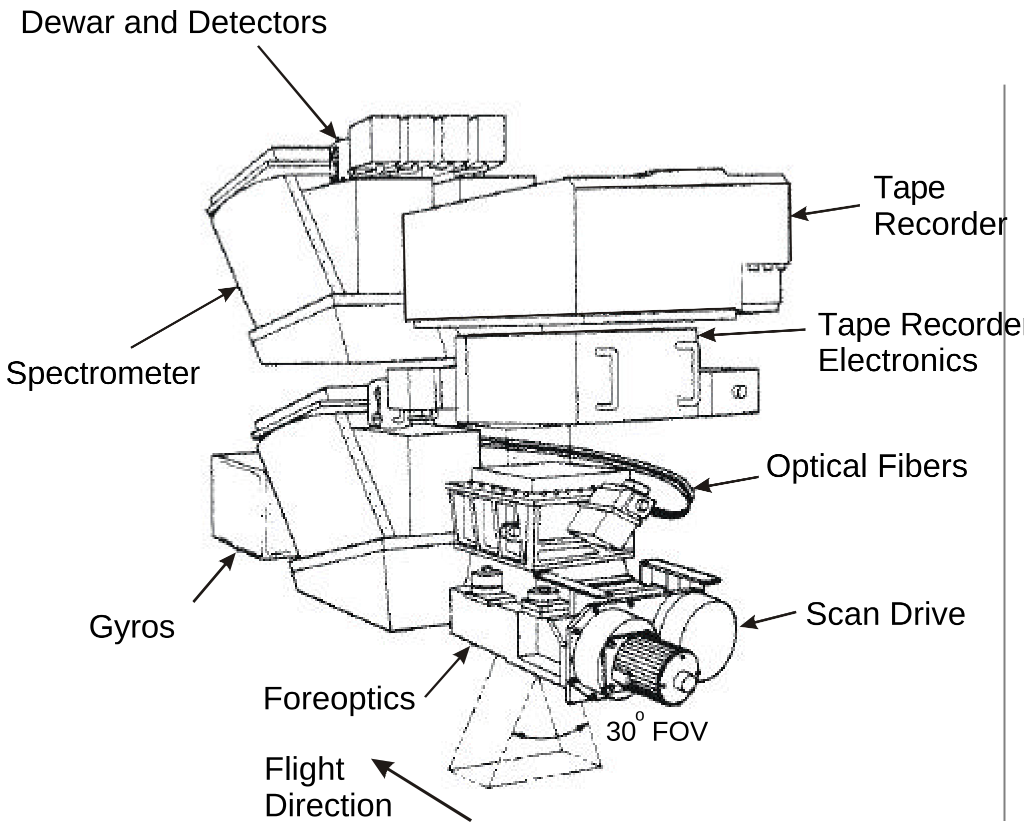


Figure 5.15 The AVIRIS Instrument. Instrument mass is 340 kg.

10 bit data encoding through 1994, 12 bit from 1995.

Silicon (Si) detectors for the visible range, and indium-antimonide (InSb) detectors for the near infrared. (Liquid Nitrogen (LN2) cooled detectors)

30 degrees total field of view (full 614 samples); 1 milliradian Instantaneous Field Of View (IFOV, one sample), calibrated to within 0.1 mrad

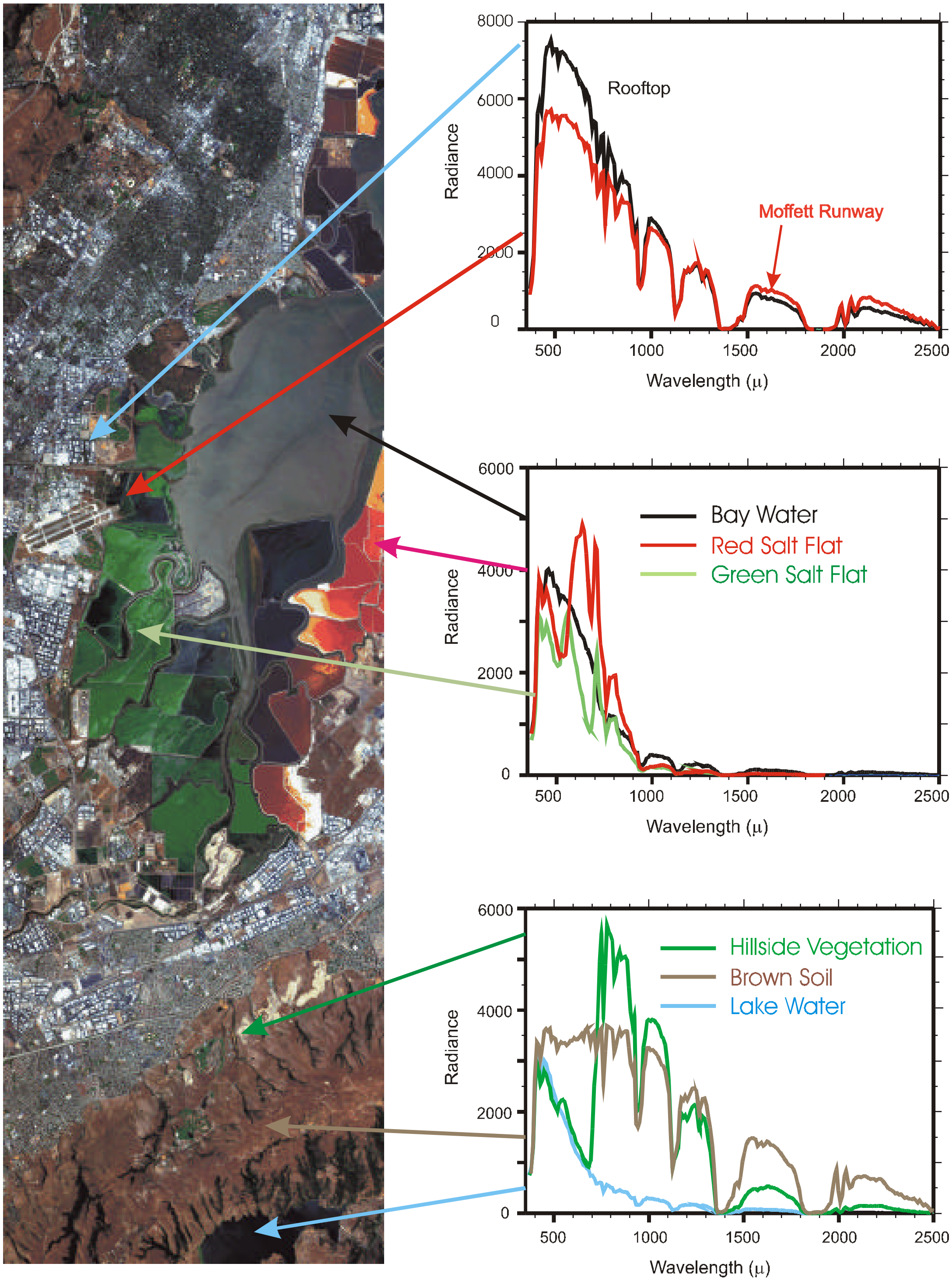


Figure 5.16 This image from AVIRIS shows elements of a scene acquired on August 20, 1992. The mission was flown on a NASA ER-2 plane at an altitude of 20,000 meters (65,000 feet) over Moffett Field, California, at the southern end of the San Francisco Bay. The image is a roughly 'true' color representation of the data. Blue: 458.46 nm, Green: 557.07 nm, Red: 655.84 nm (Bands 10, 20, and 30). The red area is real; it is due to the presence of 1-centimeter-long red brine shrimp in the evaporation pond.

F Problems

1. What wavelength does the 'IR ledge' for vegetation occur at? Is this in the bandwidth of a silicon detector?

2. When was the first Landsat launched?

3. How many spectral channels are used for the Thematic Mapper instrument? Over what wavelength ranges?

4. How wide is a standard Landsat 7 image? What is the spatial resolution for the 6 reflective bands? What is the spatial resolution for the thermal band? How many pixels wide does this make an image in the reflective band?

5. How does SPOT differ from Landsat 7?
   Spatial resolution (spectral bands, high-resolution panchromatic band)
   Wavelength for high-resolution panchromatic band
   Orbit
   Wavelengths of spectral bands
   Dynamic range

6. What is the nominal orbit for Landsat 7? (altitude, inclination, local time for equator crossing)

7. How long is the repeat cycle for Landsat 7?

8. What is the dynamic range for the visible detectors on Landsat 7 (6, 8, or 10 bits)?
(you may need to go to the NASA/GSFC Landsat site on the WWW)

9. What is the nominal spectral resolution for AVIRIS (compare to Landsat).